Late Wisconsin Glacier Surface Elevations and Flow Directions from the Beartooth Plateau to the Clarks Fork Valley, Wyoming

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INTRODUCTION

At its maximum, Late Wisconsin glaciation of North America resulted in ice coverage stretching from the Atlantic to the Pacific. The continuous span of ice was divided into two glaciers the Laurentide Ice Sheet, which covered the northeastern and north-central portions of North America, and the Cordilleran Glacier Complex which occupied the northwest (Flint, 1971). The Cordilleran Glacier Complex only reached as far south as the Columbia Plateau in Washington, but south of this limit of continuous ice, at least 75 separate glacial areas were centered on highlands (Flint, 1971). These highlands, the high alpine ranges in the western United States, included the near-coastal Pacific Mountain system and the Interior Rocky Mountain system (Porter and others, 1983). Instead of forming massive ice sheets, the glaciers situated in these mountains and plateaus were either valley glaciers, groups of valley glaciers, complexes, or ice caps. Of the total volume of ice situated in the Rocky mountain glacial complexes, most was contained in large ice caps and ice fields, rather than in valley glaciers. The mountains in northwestern Wyoming and adjacent states were home to one such glacial complex. These mountains and plateaus comprise the Yellowstone - Teton - Wind River highlands. Within them lies "the largest single area of former glaciation" in the western United States (Porter and others, 1983).

The Beartooth Plateau is a part of these highlands, located on the border of Montana and Wyoming, northeast of Yellowstone National Park. During the Late Wisconsin, the Beartooth Plateau had an ice cap of its own (Flint, 1971). The uppermost, smooth plateau surface is now characterized by periglacial landforms such as tors and patterned ground, and is virtually devoid of any glacial erosional forms. In sharp contrast to this topography, the northeast and southwest sides of the plateau have been carved out, incised by valley glaciers. The land bordering the plateau's uppermost surface is riddled with cirques, tarns, U-shaped valleys, roches moutonnées, glacially polished bedrock, striations, and ice-transported boulders and erratics. This landscape stretches from near the Beartooth crest south to Clarks Fork valley.

PURPOSE

The purpose of this study is to determine flow directions, surface elevation, and thickness of the Beartooth Plateau ice as it radiated from the plateau toward Clarks Fork of the Yellowstone River. With this information, the former glacial system of the area can be reconstructed. Knowledge of ice flow directions is used to determine whether ice flow was topographically constrained or unconstrained. Topographically constrained ice indicates the presence of valley glaciers, whereas unconstrained flow characterizes the sheet flow of ice caps (Sugden, 1976). If all the data represented maximum conditions, flow directions (constrained or unconstrained) would show the transition from sheet flow to stream flow in an ice cap complex. More realistically, flow directions indicate which direction the ice was taking during both maximum conditions and retreat, providing later ice flow did not destroy any earlier traces.

Ice surface elevations are helpful in studying the effects of ice thickness on the erosional ability of an ice mass. "It is reasonable to suppose that effective erosion beneath an ice sheet can only take place when the basal ice is at the pressure melting point. Since ice temperatures rise with depth, conditions are far more favorable for basal melting where ice is thicker...The inverse argument is that ice sheets are likely to be frozen to their beds when the ice is thin, especially where nourished in a cold continental climactic regime" (Sugden, 1976). Selectivity of glacial erosion is a function of ice thickness and basal characteristics. The right conditions make it possible for land once covered by ice to appear unglaciated. Another use for ice surface elevations is to use them to determine whether or not some visually ambiguous areas were overridden by glacial ice. Some nunataks are obvious - they take the shape of a horn, but others may not be so distinct. A nunatak may have been inundated by ice during a past glacial period, and left untouched by the most recent. In order to create a correct reconstruction of a former glacial system, estimations based on data obtained from unmistakable sources must be made for the areas that are not as clear.

FIELD OBSERVATIONS

The area of investigation is located in the Muddy Creek, Beartooth Butte, and Deep Lake 7.5 minute Quadrangles of Wyoming. Combined, these include the southernmost portion of the Beartooth Plateau and much of the glaciated highlands which slope south toward Clarks Fork (see Figure 1). Specific attention was placed on the area between Beartooth Butte in the west to Tibbs Butte in the east, and from the Montana-Wyoming border in the north, to the edge of Clarks Fork valley in the south. The map shown in Figure 1 shows more area than was covered in the field, particularly to the far west, east, and south.

Several methods were used to determine ice surface elevations. If an area has been glaciated, the landscape that results is enough proof that ice once covered the area. Questionable terrain would include, high peaks, buttes, and ridges that rise significantly above the surrounding topography, and jagged, rough, extremely weathered knobs and hilltops. Such areas could have been high enough to escape inundation by ice. If so, the elevation of the ice surface at this point must have been somewhere below the summit elevation of the feature. Examination of a lower, glaciated area, upslope to the higher, unglaciated one may provide an elevation at which the effects of glacial flow and erosion no longer appear. For example, although the landscape surrounding Beartooth and Clay Buttes bears signs of glacial erosion and aerial scour, the buttes themselves appear to have remained free of ice flowing from the Beartooth Plateau. Off the northernmost point of Beartooth Butte (elev. 10,514 ft / 3,205 m), the highest evidence of glacial flow occurs at an elevation of 10,280 ft (3,133 m). Granite erratics in a medial moraine were deposited on a shale core part-way up the butte. About 3 km to the south in the depression between Beartooth and Clay Buttes, more granite erratics occur at an elevation of 10,020 ft (3,055 m). The erratics crossed the depression from the northwest to the southeast, forming a narrow train of boulders. Knowing these two limits, the slope of the ice surface from the north end of Beartooth Butte to the south end can be determined. Ice surface elevation dropped 260 ft (79 m) over 3 km, so the slope here was approximately 87 ft/km (26m/km).

In the southeast portion of the field area, similar ice limits occur around Sawtooth Mountain (elev. 10,252 ft / 3,126 m) and the hill to the southwest (9,919 ft / 3,024 m). The ragged, rocky spires of Sawtooth Mountain provide evidence that ice did not overtop the mountain. Rarely do such features survive inundation by ice. The upper ice limit was approximately 9,800 ft (2,987 m) on Sawtooth Mountain and about 9,600 ft (2,927 m) on the hill southwest of Sawtooth Mountain. Here, the ice surface elevation dropped about 200 ft (60 m) over a distance of 2 km, therefore, the ice surface slope here was approximately 100 ft/km (30 m/km). In Figure 1, the 9,700 foot contour lies at the same general elevation as the land in the valley between the Sawtooth Mountain and the hill to the southwest. Here, a peat bog lies in the depression as well as a train of ice transported boulders trailing south from the east side of Sawtooth Mountain indicating that ice did find its way up into the valley, possibly winding around the mountain from the northeast. With the exception of the ice west of Sawtooth Mountain that apparently made its way to Deep Lake, it appears that no ice covered the high areas in the extreme southeast portion of Figure 1. Other nunataks (shown in Figure 1) occur in the central portion of the field area, approximately 1 km north of Bird Mountain. These knobs appear ice free because they are deeply weathered and crumbling, lacking the fresh, pink, scoured and polished appearance of bedrock on nearby, smaller hills. Ice surface elevation on these hills was 9,960 ft (3,037 m) and 10,000 ft (3,049 m).

Another way to approximate ice surface elevation is to note the elevation of high areas that the ice covered. In such cases, the upper limit of the ice had to be at , or above, the elevation of the mountain or hill that it covered. About 3 km directly east of Beartooth Butte, a cliff stretches upward from the eastern shore of Beauty Lake to an elevation of 10,064 ft (3,068 m). At the top of this cliff is a pink, granite outcrop that was rounded and smoothly polished. More polish and glacial striations occur further southeast. On Bird Mountain (9,924 ft / 3,026 m) and Table Mountain (8,761 ft / 2,671 m), erratics and ice-transported boulders provide evidence of glaciation. Granitic ice-transported boulders occur atop Bird Mountain along with erratic pieces of reddish sandstone. One particular ice-transported boulder (about 10 m long, 4 m wide, and 4m high) is smooth and rounded. Granitic erratics also occur on the summit of Table Mountain, located in the southwestern portion of the of the field area. Here, large chunks of limestone from the point of Table Mountain appear to have been plucked from the point and moved to the southeast by an ice mass passing over the summit.

To determine flow directions of ice radiating southward from the Beartooth Plateau, orientations of glacial striations were used. Two distinct sets of flow directions occur in this area. One set is oriented perpendicular to the edge of the Beartooth Plateau. These range from S45°W in the west, through due south in the central portion, to S44°E in the eastern section of the map (figure 1). Many of the striations, especially those on top of high hills, are oriented in this way. Another distinct set of striations follows valley curvature and topographical trends, as in the valley upstream of Night Lake, approximately 5 km east of Beartooth Butte. Here, the striations are oriented down valley. The same is true for ones located within the broad central valley trending east-west, south of Beartooth Lake and Island Lake.

DISCUSSION

Glacial erosion can be selective under ice. The sharp contrast between the smooth, relatively flat surface of the highest portion of the upper Beartooth Plateau and the modified, carved landscape to the south is similar to a landscape of selective linear erosion. This develops where "ice erosion has been concentrated in a trough or series of troughs and has left the intervening slopes or plateau unmodified" (Sugden, 1976). This type of landscape develops beneath ice sheets, leaving the intervening plateau areas "regolith covered and devoid of glacial erosional forms," with "fragile rock remnants like tors of possible pre-glacial age surviving on the interfluves" (Sugden, 1976). This leads to the idea of erosion only occurring where there is basal sliding. In turn, basal sliding only occurs where the ice is thick enough for the pressure melting point to be reached. "Landscapes of selective linear erosion form an intermediate category where basal ice is at the pressure melting point only in troughs," remaining "below the pressure melting point over the sites of intervening interfluves" (Sugden, 1976). This would explain the juxtaposition of two vastly different glacial landscapes in the area of the Beartooth Plateau if, in fact, the upper plateau was covered by cold-based ice, with warm-based ice flowing from the plateau edge to the Clarks Fork.

Another alternative is that ice only reached as far as the cirque headwalls that circumvent the highest part of the plateau (see trace outlining possible ice free areas in Figure 1). This would leave the upper plateau devoid of ice, requiring modification of the ice surface contours and the estimated ice limits on Tibbs Butte and the high land to the east, north of Deep Lake. The approximate elevation of the top of the cirque headwalls ranges from 11,000 ft (3,354 m) in the north-central portion to 10,600 ft (3,232 m) in the northeastern portion of Figure 1. Glaciers are presently located in the north facing cirques south of Emerald Lake, where the ice, even now, stretches as high as 11,200 ft (3,415 m). It is difficult to comprehend how ice may have only reached as high as the top of the cirque headwalls during the late Wisconsin glacial period, when, even today, glaciers exist at this elevation. The other alternative, therefore, presents the possibility that there might have been ice, thin ice, or at least a big pile of snow on the high plateau, supported by the possibility that periglacial landforms may remain intact under thin, cold-based ice sheets.

"Since ice temperatures rise with depth, conditions are more favorable for basal melting where ice is thicker" (Sugden, 1976). Locating nunataks made it possible to calculate some average ice surface slopes both in the western and eastern portions of the map area. The altitudes of the contours on the ice surface "are based on nunataks and maximum altitudes of glaciated uplands" (Porter and others, 1983). They show that the ice was considerably thinner on the high plateau (thin or absent depending on the theory), and thicker to the south (400 to 3,000 feet or 122 to 915 meters in the Clarks Fork Valley!). This evidence suggests that the plateau ice was absent or cold-based and frozen to its bed allowing no flow, and therefore no glacial erosion on the plateau.

The two main sets of flow directions shown in Figure 1 indicate signs of both valley glacier forms and ice sheet forms, which appear to have evolved at different times (Sugden, 1976). The flow directions which radiate from the Beartooth plateau from S45°W to S45°E represent a phase of cap flow. These directions, found at some of the highest elevations, indicate flow in the upper part of the ice during maximum glaciation. The other set of flow directions indicates a later period when topography constrained the glaciers. These glaciers were confined to valleys, as indicated by the striations that they etched in directions parallel to valley orientations. The presence of cirques along the edge of the upper Beartooth Plateau also supports the evolution of a glacial phase other than ice cap growth. "Since there is no reason to suppose that cirques form beneath ice sheets, such situations have long been accepted as representing different phases of mountain and ice sheet glaciation" (Sugden, 1976). Pinedale glaciers, named to represent the last glaciation occurring in this area, were near their maximums about 20,000 years ago (Porter and others, 1983) and were characterized by ice cap forms. Over the next 10,000 years, the ice caps reduced to valley glaciers, and glacial retreat followed soon after.

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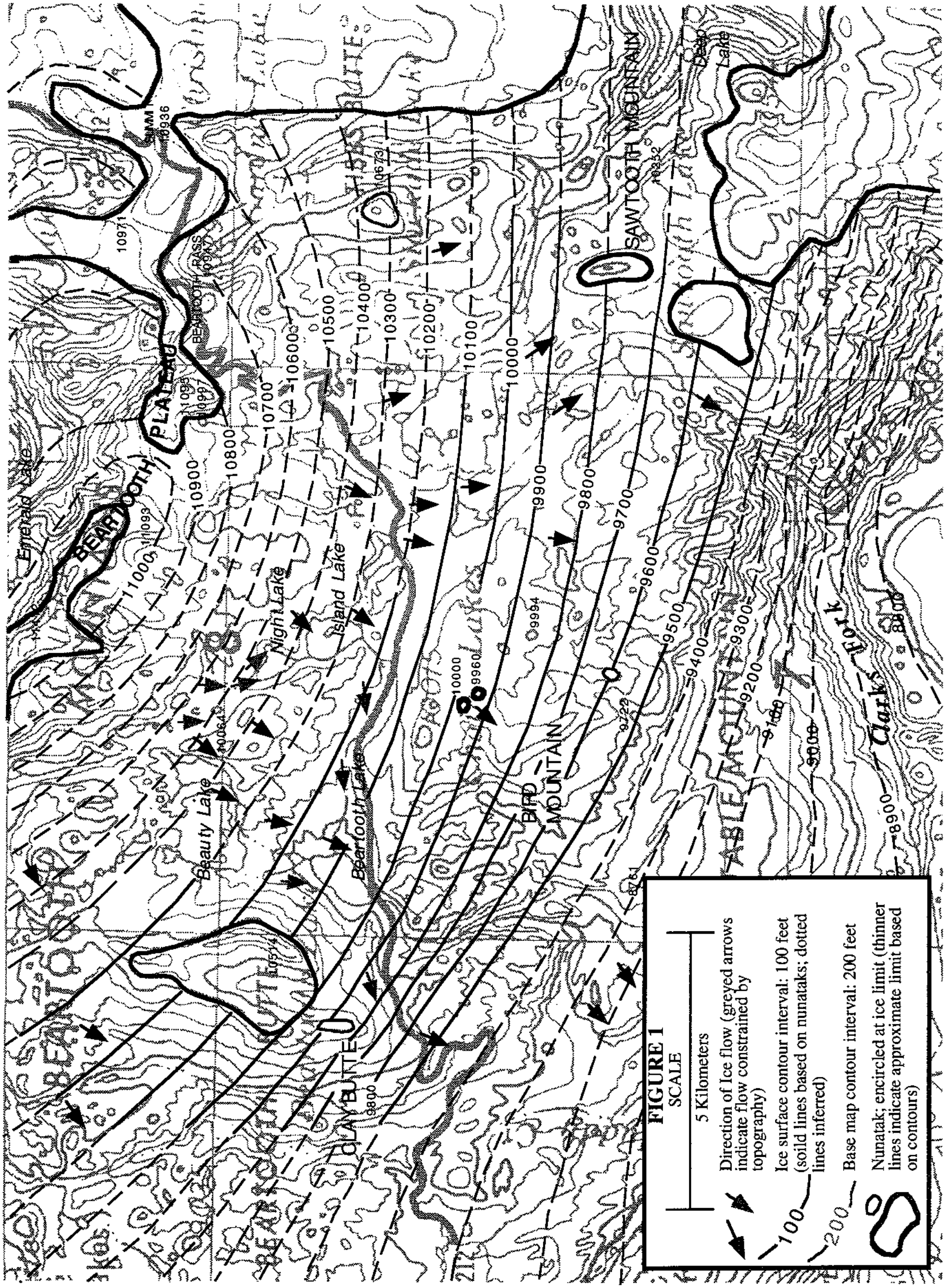
FIGURE 1
SCALE
5 Kilometers
Direction of Ice flow (greyed arrows indicate flow constrained by topography)
Ice surface contour interval: 100 feet (solid lines based on nunataks; dotted lines inferred)
Base map contour interval: 200 feet
Nunatak; encircled at ice limit (thinner lines indicate approximate limit based on contours)
BEARTOOTH PLATEAU
SAWTOOTH MOUNTAIN
BIRD MOUNTAIN
CLAY BUTTE
Beauty Lake
Night Lake
Island Lake
Beartooth Lake
Emerald Lake
Deep Lake
Clarks Fork